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Improvement of Biomethane Production Yield from Palm Oil Mill Effluent using Ozonation Process

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Abstract

Biological methane production from the raw and the ozonated palm oil mill effluent (POME) were conducted in 0.5 L batch reactors using UASB mixed culture as a microbial seed. All measurements were conducted in duplicate and experimental conditions with varying POME concentrations in the range of 3,000 to 40,000 mg L^{-1}, under mesophilic condition (37°C) and pH 7.0. Comparative results of methane production from the raw POME versus the ozonated POME indicated that the ozone pretreatment of POME (mg COD: mg ozone = 102.78) elevated the biodegradability of the POME constituents and enhanced effectively the methane production yield and rate for most cases. The kinetic parameters data were fitted with modified Gompertz equation. The ozonated POME concentration of 15,000 mg L^{-1} gave the maximum methane production potential of 624.4 mL and yield of 273.8 mL g^{-1} COD. The concentrations of volatile fatty acids and ethanol were negligible at the highest methane production yield.

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Keywords: methane; palm oil mill effluent; ozonated POME; mesophilic

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1. Introduction

Industries directly depend on fossil fuel resources (e.g., coal, natural gas and petroleum). Since the fossil resources cannot be regenerated, they will be soon exhausted with the increasingly huge consumption rate [1]. To prepare for a long term impact of the rise of fossil fuel price and reduce the environmental impact from the use of fossil fuels (e.g., air pollution and global warming). Anaerobic digestion process for reduction of the POME is advantageous before POME is released to the environment. Therefore, the current study is intrigue on the anaerobic process capable of reducing the pollution in the POME and generating the biogas at the same time. The palm oil industry in Thailand has been rapidly expanded, and thus generates a large amount of highly polluting POME. Typically, a ton of crude palm oil production requires 5-7.5 tons of water; over 50% of which ends up as POME [2]. Since the brown liquid POME contains high biodegradable organic content about 95-96% water, 0.6-0.7% oil and 4-5% total solids. pH 4-5, hot (80-90°C), nontoxic (no chemicals are added during oil extraction), has high biodegradable organic content (COD 50,000 mg L^{-1}, BOD 25,000 mg L^{-1}) and recalcitrant organic compounds (e.g., long chain fatty acids, lignin and tannin) [3]. The partial ozonation pretreatment of POME is ideal to breaks down the recalcitrant organic matters to be more biodegradable. This research aimed to evaluate the effectiveness of the partial ozonation of POME on the enhancement of the methane production under mesophilic condition. The comparative performance of raw and ozonated POME fermentation was evaluated based on kinetics data

2. Materials and Methods

2.1. Microbial seed

Microbial seed was obtained from a full-scale up-flow anaerobic sludge blanket (UASB) (Malee Sampran Co., Thailand). Granular seeds with diameter >0.5 mm were washed with tap water and were sampled for total volatile solid (TVS) analysis.

2.2. Palm oil mill effluent (POME)

The raw POME was collected from the stabilization pond (Sooksomboon Palm Oil Co., Ltd. Chonburi, Thailand). Raw POME exhibits dark brown color, a temperature of 70-80°C, and pH 4.4-4.7. Suspended solids in raw POME were allowed to settle down for one day (24h) before its storage in a cold room at 4°C to use. The ozonated POME was prepared from the pre-settled POME with ozone loading rate of 300 mg h^{-1} (mg COD: mg ozone = 102.78).

2.3. Experiment setup

The batch methane fermentation was set up in 500 mL Scott Duran bottles. All experiments were fixed 25% of microbial seed of each reactor and varied 75% POME concentrations of 3,000 to 40,000 mg COD L-1. After placing POME and microbial seed in the reactor, pH was adjusted to 7.0 by 6 M NaOH or conc. H_3PO_4 and then capped tightly with the silicone stopper and flushed with nitrogen gas to create an anaerobic condition. The batch fermentation was conducted at 37°C with incubator shaking 150 rpm. All experiments were performed in duplicate. Gas samples were taken once in every 4 h and the total volume of gas was measured using water displacement method. Mixed liquor samples were analyzed for pH, chemical oxygen demand (COD) [4] and volatile fatty acids (VFAs) [5].

2.4. Analytical methods

Gas composition (H_2, CH_4, and CO_2) in the headspace of batch reactor was measured on a gas chromatograph (Shimadzu GC-2014, Japan) equipped with thermal conductivity detectors (TCD) fitted with stainless steel column packed with Unibeads C (80/100 mesh). Helium was used as a carrier gas. The temperatures of the injection port, column and detector were 120, 70 and 150°C, respectively. Volatile fatty acids (VFAs) and ethanol were analyzed by a gas chromatograph (Shimadzu GC-2010, Japan) equipped with a flame ionization detector (FID) fitted with Stabilwax DA capillary column (Restek, USA). Hydrogen, air-zero, nitrogen and helium were used as a carrier gas. The temperature of the injection port, column and detector were set up at 230, 80 and 250°C, respectively.

2.5. Kinetics of batch methane production

Kinetics of methane production was calculated from the cumulative methane production versus time data of each batch experiment fitted with the modified Gompertz equation [5].

$$H = H_{\max} \cdot \exp\{-\exp\left[\frac{R_{\max} \cdot e}{H_{\max}}(\lambda - t) + 1\right]\} \quad (1)$$

where, H is the cumulative volume of methane production (mL), t is time of fermentation (h), H_{max} is the methane production potential (mL), R_{max} is the maximum methane production rate (mL h^{-1}), λ is lag phase (h) and e is a constant (2.71828). Methane yield is calculated by dividing the methane production potential by the amount of total COD removed.

3. Results and discussions

3.1. Kinetics of methane production

The experiment was setup with varied POME concentration and fixed pH at 7.0. The pH increased after 84 h incubation was observed in the narrow ranges of 7.2-7.6 for the raw POME and 7.0-7.7 for the ozonated POME. Total cumulative methane was increased with the increase of POME concentration (Fig. 1a and b). POME concentrations strongly affected the fermentation kinetics (e.g., H_{max}, R_{max}, λ, and Y) were shown in Table 1. H_{max} increased as POME concentration increased from 3,000 to 10,000 mg L-^{1} and the ozonated POME reached the highest level of 624.4 mL. While, R_{max} increased and then decreased at POME concentration higher than 10,000 mg L^{-1}. H_{max} and R_{max} tended to decrease when the POME concentration increased. The POME concentration of 15,000 mg L^{-1} gave the highest methane yield (Y) of 177.8 and 273.8 mL g^{-1}COD for the raw POME and the ozonated POME, respectively (Table 1). The results indicated that the fermentation condition was suitable for the biomethane production, and partial ozonation pretreatment improved the yield by 54%. There is significant difference of the soluble COD removal efficiency between the ozonated (38.9%) and the raw POME (24.2%) at the highest methane yield. This result indicates that partial ozonation pretreatment of POME breaks down the recalcitrant organic matters to be more biodegradable in term of soluble COD. Minimal VFAs and ethanol were detected as the end fermentative products trended to decrease of POME concentration from 3,000 to 10,000 mg L^{-1} and then to increase when the POME concentration increased from 15,000 to 40,000 mg L^{-1} for both POME. Little concentration of VFAs and ethanol at POME concentration of 10,000 mg L^{-1}, were detected for both POME.

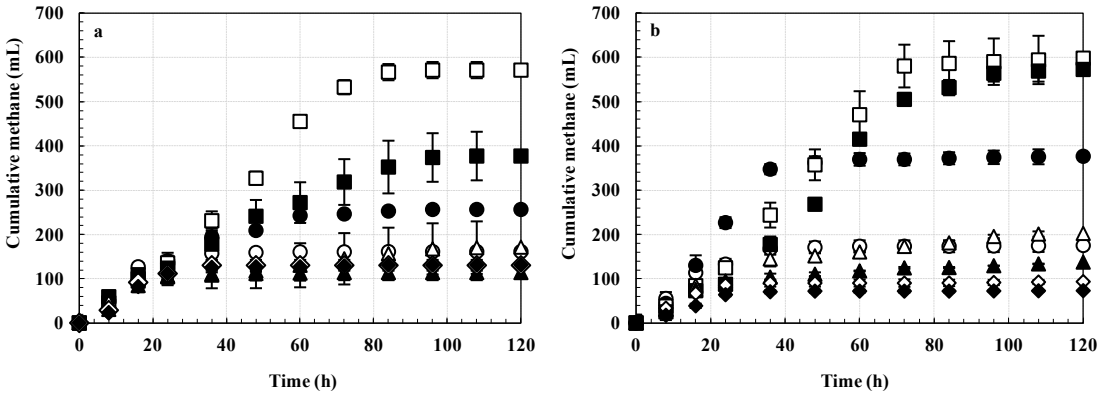

Fig. 1. (a) cumulative methane production of raw POME; (b) ozonated POME with the initial concentrations of 3000 (●), 6,000 (○), 10,000 (■), 15,000 (□), 20,000 (▲), 25,000 (Δ), 32,000 (♦) and 40,000 (◇). The data and I-bars represent mean values and standard deviation of duplicate experiments.

Table 1. Kinetic parameters of methane production with varied POME concentrations.

[COD] (mg L^{1})	H_{max} (mL)		R_{max} (mL h^{-1})		λ (h)		Y (mL g^{-1}COD)	
	Raw POME	Ozonated POME	Raw POME	Ozonated POME	Raw POME	Ozonated POME	Raw POME	Ozonated POME
3,000	159.4±2.7	173.2±14.9	9.9±2.0	7.7±1.5	2.7±0.6	1.2±0.8	110.3±40.2	124.5±41.0
6,000	254.1±2.6	375.0±13.2	6.6±1.4	14.3±1.8	3.0±2.6	6.7±1.0	160.6±43.0	153.3±26.2
10,000	607.4±19.4	624.4±50.3	9.6±0.2	11.0±1.8	10.0±0.7	12.5±3.3	157.0±11.7	242.0±27.8
15,000	400.6±58.8	608.2±18.9	5.1±0.8	9.6±0.3	0.0±0.0	16.3±0.1	177.9±41.3	273.8±27.1
20,000	156.8±61.3	193.7±12.5	4.5±0.6	4.2±1.4	0.0±0.0	0.0±0.1	41.1±16.3	51.1±2.5
25,000	112.8±10.4	126.8±2.4	7.6±0.2	4.1±1.4	3.9±0.8	0.1±0.0	21.2±2.1	22.4±1.0
32,000	129.8±12.4	90.8±7.3	7.9±0.3	5.5±0.1	4.3±0.6	2.1±1.0	24.4±3.5	14.9±1.0
40,000	129.0±8.2	72.2±3.0	7.5±1.1	3.6±0.1	4.9±0.1	3.8±0.9	9.3±1.2	14.5±1.6

4. Conclusion

This study demonstrated that the ozonation pretreatment of the POME promote the biodegradability of POME constituents and kinetics of biomethane production. The biomethane yield was increased by 54%, when the POME was pretreated by partial ozonation.

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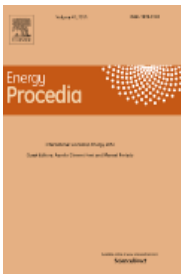

Biography

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